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# MULTIMEDIA UNIVERSITY

## FINAL EXAMINATION

TRIMESTER 2, 2017/2018

**EOP2016 – FUNDAMENTALS OF OPTICS**  
( OPE )

12 MARCH 2018  
9:00 – 11:00  
( 2 Hours )

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### INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 8 pages with 3 Questions only.
2. Attempt **THREE** out of **THREE** questions. Distribution of the marks for each question is given.
3. Please print all your answers in the Answer Booklet provided.

**Question 1**

(a) Ibnu Al-Haitham was considered the father of modern optics and he was also referred to as the first true scientist. Describe three of his most significant contribution related to the area of optics.

[3 marks]

(b) An optical ray of wavelength of 550 nm is traveling through the air. It is striking a water (refractive index of 1.33) surface, at an angle of  $40^\circ$ . Calculate

- (i) The angle of refraction
- (ii) The velocity of the optical ray in the water
- (iii) The wavelength of the optical ray in the water

[6 marks]

(c) When a light beam strikes a glass-air boundary, what is the critical angle if  $n_{glass} = 1.5$ ? Given that the refractive indices of air and the glass are 1.0 and 1.5 respectively.

[2 marks]

(d) “*It seems as though we must use sometimes the one theory and sometimes the other, while at times we may use either. We are faced with a new kind of difficulty. We have two contradictory pictures of reality; separately neither of them fully explains the phenomena of light, but together they do*” – Albert Einstein.

The quote above described the wave-particle duality concept. Give three phenomena of light that can only be described by the wave theory and three phenomena that can only be described using the particle theory of light.

[6 marks]

(e) Suppose a laser diode material's energy gap equals to 0.8052eV. At what wavelength does this laser diode radiate? [1eV=1.602x10<sup>-19</sup>J, Plank's constant = 6.6 x 10<sup>-34</sup>J.s]

[3 marks]

**Continued...**

**Question 2**

(a) An object 3 cm high is placed 20 cm from a convex spherical mirror, each of 10-cm focal length. Determine the position and nature of the image.

[7 marks]

(b) Determine the focal lengths and the principal points for a 6 cm thick, biconvex lens with refractive index of 1.54 and radii of curvature of 20 cm, when the lens caps the end of a long cylinder filled with water ( $n = 1.33$ ). The equations for the focal lengths and also the positions of the principal planes are as follows:

$$\frac{1}{f_1} = \frac{n_L - n'}{nR_2} - \frac{n_L - n}{nR_1} - \frac{(n_L - n)(n_L - n')}{nn_L} \frac{t}{R_1 R_2}$$

$$f_2 = -\frac{n'}{n} f_1$$

$$r = \frac{n_L - n'}{n_L R_2} f_1 t$$

$$s = -\frac{n_L - n}{n_L R_1} f_2 t$$

[8 marks]

(c) Figure Q2-(c) shows reflection at a spherical surface. The inset shows the sign convention for ray angles where  $y$  and  $y'$  are positions,  $\alpha$ ,  $\alpha'$ ,  $\theta$ ,  $\theta'$  and  $\phi$  are angles,  $C$  is center of curvature and  $R$  is radius of curvature. Determine the  $2 \times 2$  reflection matrix.

[8 marks]

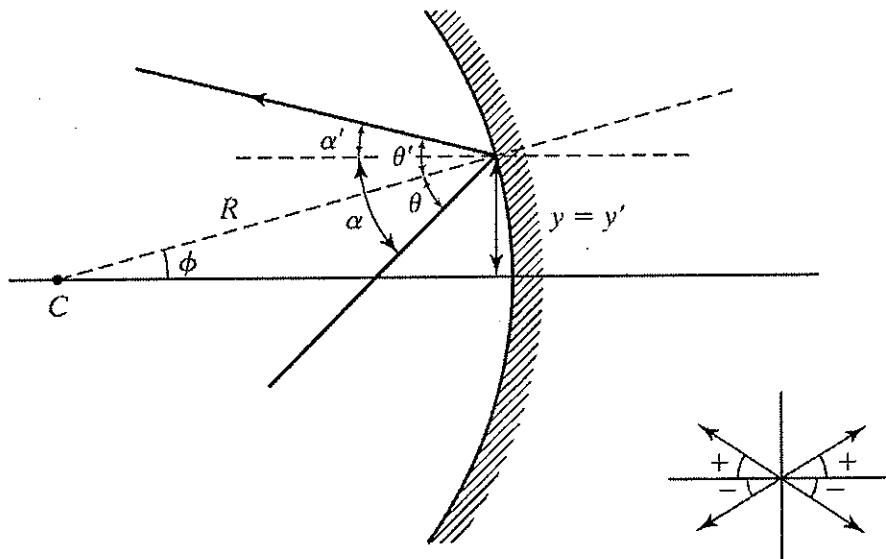


Figure Q2-(c)

Continued...

(d) A converging lens with a focal length of 7.00 cm forms a 1.30 cm tall image of a 4.00 mm tall real object that is to the left of the lens. The image is erect. Find the locations of the object and the image and determine whether the image is real or virtual.

[7 marks]

(e) For a harmonic wave given by

$$y = 10 \text{ cm} \sin[(628.3/\text{cm})x - (6283/\text{s})t]$$

Determine:

- i. Wavelength
- ii. Frequency

[3 marks]

(f) Determine the result of the superposition of the following harmonic waves:

$$E_1 = 7 \cos(\pi/3 - \omega t)$$

$$E_2 = 12 \sin(\pi/4 - \omega t)$$

$$E_3 = 20 \cos(\pi/5 - \omega t)$$

The related equations for superposition of waves are as follows:

$$E_0^2 = \left( \sum_{i=1}^N E_{0i} \sin \alpha_i \right)^2 + \left( \sum_{i=1}^N E_{0i} \cos \alpha_i \right)^2$$

$$\tan \alpha = \frac{\sum_{i=1}^N E_{0i} \sin \alpha_i}{\sum_{i=1}^N E_{0i} \cos \alpha_i}$$

[10 marks]

**Continued...**

**Question 3**

(a) Describe what happens to unpolarized light incident on birefringent material when the optical axis (OA) is oriented as shown in each sketch in Figure Q3-(a). Comment on the following aspects: Single or double refracted rays? Any phase retardation? Any polarization of refracted rays?

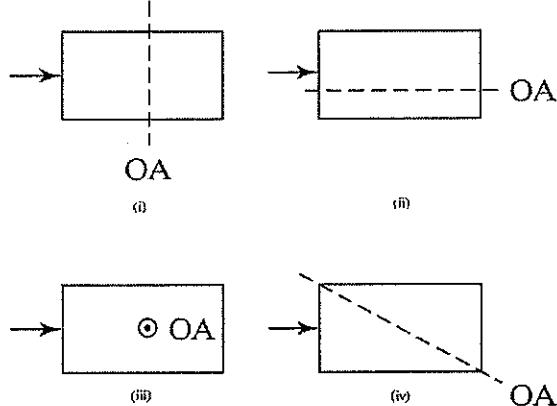


Figure Q3-(a)

[12 marks]

(b) Analyze the Jones vector given by

$$\begin{bmatrix} 3 \\ 2+i \end{bmatrix}$$

to show that it represents elliptically polarized light. Given that the equation for angle of inclination and general equation of an ellipse are as follows:

$$\tan 2\alpha = \frac{2E_{0x}E_{0y} \cos \varepsilon}{E_{0x}^2 - E_{0y}^2}$$

$$\left(\frac{E_x}{E_{0x}}\right)^2 + \left(\frac{E_y}{E_{0y}}\right)^2 - 2\left(\frac{E_x}{E_{0x}}\right)\left(\frac{E_y}{E_{0y}}\right) \cos \varepsilon = \sin^2 \varepsilon$$

[8 marks]

(c) Initially unpolarized light passes in turn through three linear polarizers with transmission axes at 0, 30 and 60, respectively, relative to the horizontal. What is the irradiance of the product light, expressed as a percentage of the unpolarized light irradiance?

[7 marks]

Continued...

(d) With an aid of a sketch, describe the operating principle of an electro-optic light beam modulator.

[8 marks]

(e) Identify one advantage and one disadvantage of an electro-optic light beam modulator.

[2 marks]

**Continued...**

## Appendix A

### Physical Constants and Units

Constant	Symbol	Value (mks units)
Speed of light in vacuum	$c$	$3 \times 10^8$ m/s
Electron charge	$q$	$1.602 \times 10^{-19}$ C
Boltzmann's constant	$k_B$	$1.38 \times 10^{-23}$ J/K
Permittivity of free space	$\epsilon_0$	$8.8542 \times 10^{-12}$ F/m
Permeability of free space	$\mu_0$	$4\pi \times 10^{-7}$ N/A <sup>2</sup>
Electron volt	eV	$1 \text{ eV} = 1.602 \times 10^{-19}$ J
Planck's constant	$h$	$6.626 \times 10^{-34}$ J·s

### Summary of Jones Matrices

#### I. Linear polarizers

$$\text{TA horizontal} \quad \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix} \quad \text{TA vertical} \quad \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix} \quad \text{TA at } 45^\circ \text{ to horizontal} \quad \frac{1}{2} \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}$$

#### II. Phase retarders

General $\begin{bmatrix} e^{i\phi_x} & 0 \\ 0 & e^{i\phi_y} \end{bmatrix}$			
QWP, SA vertical	$e^{-i\pi/4} \begin{bmatrix} 1 & 0 \\ 0 & i \end{bmatrix}$	QWP, SA horizontal	$e^{i\pi/4} \begin{bmatrix} 1 & 0 \\ 0 & -i \end{bmatrix}$
HWP, SA vertical	$e^{-i\pi/2} \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$	HWP, SA horizontal	$e^{i\pi/2} \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$

#### III. Rotator

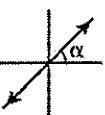
$$\text{Rotator} \quad (\theta \rightarrow \theta + \beta) \quad \begin{bmatrix} \cos \beta & -\sin \beta \\ \sin \beta & \cos \beta \end{bmatrix}$$

Continued...

## Summary of Jones Vectors

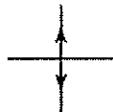
### I. Linear Polarization ( $\Delta\phi = m\pi$ )

General:

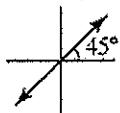


$$\tilde{\mathbf{E}}_0 = \begin{bmatrix} \cos \alpha \\ \sin \alpha \end{bmatrix}$$

Vertical:  $\tilde{\mathbf{E}}_0 = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$



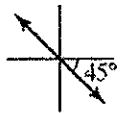
At  $+45^\circ$ :  $\tilde{\mathbf{E}}_0 = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ 1 \end{bmatrix}$



Horizontal:  $\tilde{\mathbf{E}}_0 = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$

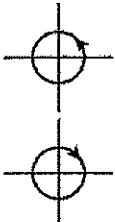


At  $-45^\circ$ :  $\tilde{\mathbf{E}}_0 = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ -1 \end{bmatrix}$



### II. Circular Polarization $(\Delta\phi = \frac{\pi}{2})$

Left:



$$\tilde{\mathbf{E}}_0 = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ i \end{bmatrix}$$

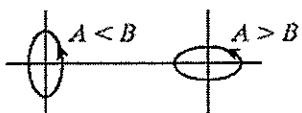
Right:



$$\tilde{\mathbf{E}}_0 = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ -i \end{bmatrix}$$

### III. Elliptical Polarization

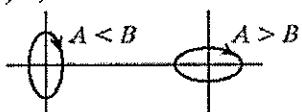
Left:



$(\Delta\phi = (m + 1/2)\pi)$

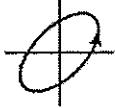
$$\tilde{\mathbf{E}}_0 = \frac{1}{\sqrt{A^2 + B^2}} \begin{bmatrix} A \\ iB \end{bmatrix} \quad A > 0, B > 0$$

Right:



$$\tilde{\mathbf{E}}_0 = \frac{1}{\sqrt{A^2 + B^2}} \begin{bmatrix} A \\ -iB \end{bmatrix} \quad A > 0, B > 0$$

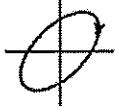
Left:



$(\Delta\phi \neq \left\{ \frac{m\pi}{(m + 1/2)} \right\})$

$$\tilde{\mathbf{E}}_0 = \frac{1}{\sqrt{A^2 + B^2 + C^2}} \begin{bmatrix} A \\ B + iC \end{bmatrix} \quad A > 0, C > 0$$

Right:



$$\tilde{\mathbf{E}}_0 = \frac{1}{\sqrt{A^2 + B^2 + C^2}} \begin{bmatrix} A \\ B - iC \end{bmatrix} \quad A > 0, C > 0$$

End of paper.

